R 702

Technical Report

CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS

November 1970

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS

Technical Report R-702

YF 51.543.006.01.007

by

R. W. Drisko

ABSTRACT

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

This d

Inf

CONTENTS

	page
INTRODUCTION	1
BACKGROUND	1
CATHODIC PROTECTION SYSTEMS	2
Magnesium Anodes	2
Fabrication	2
Installation	7
Performance	7
Zinc Anodes	10
Installation of Zinc Anodes	10
Performance	11
Zinc Anodes With Additional Leads	12
Specialized Zinc Anodes	15
Specialized Zinc Anodes With Steel Cables	22
Repairs and Fabrication	22
Performance	25
Relocation of Mooring	30
DISCUSSION	38
ANALYSIS OF MAINTENANCE AND REPLACEMENT COSTS	39
FINDINGS	50
CONCLUSIONS	50
RECOMMENDATIONS	50
ACKNOWLEDGMENT	50
REFERENCES	51

INTRODUCTION

Field activities of the Naval Facilities Engineering Command (NAVFAC) have encountered considerable difficulty and much expense in maintaining adequate protection from corrosion for buoys and ground tackle used in Fleet moorings. The rates at which the protective coatings deteriorate and the steel corrodes in seawater vary greatly in different locations throughout the Naval Shore Establishment because of differences in temperature, nature of environment, and type of service rendered. It has been stated that ". . . in certain far eastern water the average effective durability of a steel navigational buoy is only about eight years, and that even in this short life repairs to the underwater shell are required every third to fifth year."[1] Thus, a large portion of the buoy deterioration occurs where the structure is continually immersed; this is the only area where cathodic protection from corrosion can be effective. The purchase and maintenance costs of mooring chains are several times those required for mooring buoys. As a consequence, the Naval Civil Engineering Laboratory (NCEL) was asked to investigate the use of cathodic protection for protecting both the submerged portion of mooring buoys and the ground tackle used to secure them in place.

BACKGROUND

In 1964, when the present work was initiated, approximately 100 Fleet moorings were maintained by U.S. Navy Public Works Center, San Diego. The value of a typical mooring (a Mark II peg-top buoy with a riser-chain and four ground legs) was estimated to be $33,500, of which $2,000 was for the buoy and $31,400 was for the ground tackle. The estimated annual maintenance cost for each mooring was $1,600, most of which was for the ground tackle.

BUDOCKS Instruction 11153.4B of 9 April 1965 calls for (1) annual inspection of mooring buoys for damage, deterioration of corrosion, and physical condition of the ground tackle connected to the buoy, (2) lifting of bouys from the water every 3 years for painting and required repairs,

and (3) hauling out of the water, inspecting, and rehabilitating the complete mooring assemblies every 3 years where there are adverse bottom conditions and every 5 years where there are favorable bottom conditions. Public Works Center, San Diego follows the 3-year program for both buoys and ground tackle. NCEL studies[2-12] show that properly chosen and applied coating systems can provide mooring buoys with up to 5 years of protection. Although the Public Works Center, San Diego dip-coats their chains with a coal tar coating (MIL-C-18480), there are no coating systems presently available that provide lasting protection to mooring chains.

Graham[1] states that ". . . cathodic protection properly applied can and does inhibit all underwater corrosion on the shell of a buoy, and in addition effects a very material reduction in corrosion wastage in the wind and water area immediately above the true water line." Brouillette and Hanna[13] state that about half of the tidal area on steel sheet pilings can be cathodically protected. Seabrook[14] found that not only the buoy but also the bridle and swivel could be cathodically protected. He reported that prior to the use of cathodic protection it was frequently necessary to replace the bridle chain and swivel after 3 years of use.

NCEL tested[2-12] a cathodic protection system on mooring buoys in which no attempt was made to protect the chain. Periodic inspection of the test installation, however, indicated that some of the cathodic protection was being transferred from the buoys down their tight riser-chains. Because the investigation of cathodically protected mooring buoys utilized a system with magnesium anodes, they were also initially tested for protecting the mooring chain. The system was designed, however, for a simple conversion to one with zinc anodes.

CATHODIC PROTECTION SYSTEMS

Magnesium Anodes

Fabrication. A standard Fleet mooring was modified by the Public Works Center, San Diego for in-service testing of the cathodic protection system. The mooring consisted of a Mark II peg-top buoy with a riser-chain and four ground legs. Each ground leg had a sinker block located 135 feet from the ground ring and an anchor located 90 feet from the sinker block. Figure 1 shows the layout of the ground tackle with the location of the anodes and remote ground cables indicated.

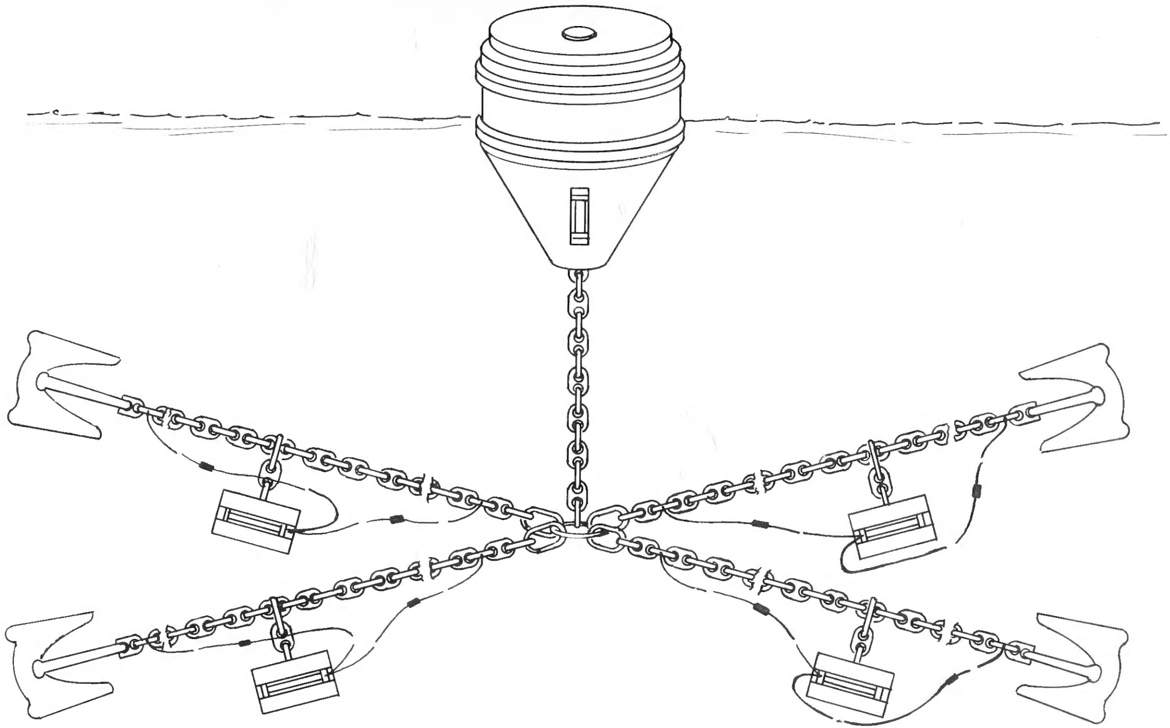

Figure 1. Design of initial cathodic protection system utilizing magnesium anodes.

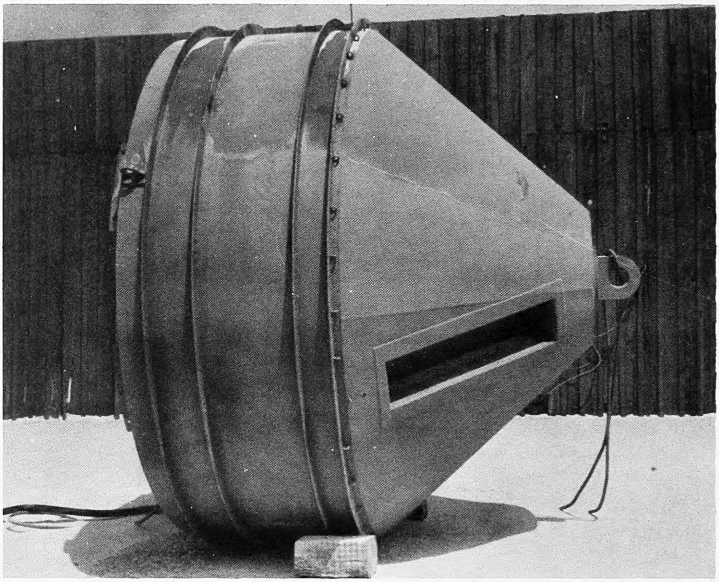

Figure 2. Test mooring buoy during sandblasting.

Two sea chests were built into opposite sides of the buoy cone, each to house a cathodic protection unit. The modified buoy was sandblasted to white metal (Figure 2) and coated with the phenolic mastic coating system described in Reference 3. The automatic control heads were bolted to threaded studs located inside the sea chests, and 80-pound magnesium anodes were secured between them and the lower mounting brackets (Figure 3). Nylon spacers were used to isolate the anodes electrically from the buoy; thus, current from the anodes had to pass through the control heads and the connected ground cables before reaching the buoy. Each of the two ground cables was threaded through a series of chain links that were welded to the bottom flange and then was welded to the flange at a point opposite the sea chest from which it came (Figure 4). Immediately before placing the buoy in service, a square-foot section of coating on the underwater portion of the buoy was sandblasted to bare steel (Figure 4), giving an exposed steel specimen on which the effect of cathodic protection could be determined visually.

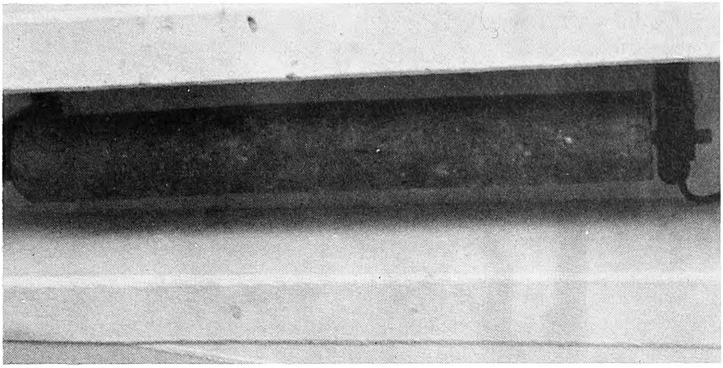

Figure 3. Cathodic protection unit in sea chest in buoy.

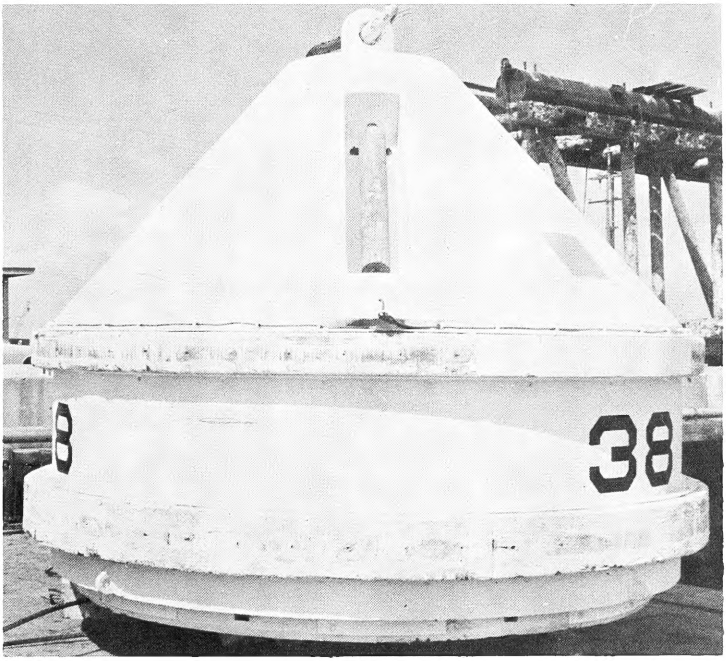

Figure 4. Inverted test buoy showing the square-foot area of bare steel on lower left of cone and location of the ground cables.

Four concrete sinker blocks were specially fabricated to hold the cathodic protection units for the ground legs. Each sinker block was prepared in a wooden form with a slot cut out to house a unit. Three and one-half 2-1/4-inch chain links were cast into the block as shown in Figure 5. Threaded J-bolts used to secure the cathodic protection equipment in place were also cast into the concrete. A cathodic protection unit similar to those on the buoy was attached to each of the sinker blocks. Each control head had two 100-foot ground cables of no. 2 neoprene-insulated, stranded copper wire attached to them.

The riser-chain and ground legs used on the mooring were sandblasted to white metal. The riser-chain and three of the four ground legs were coated with cold-applied coal tar coating MIL-C-18480A; the fourth leg was allowed to remain bare during the test to determine the differences resulting from the cathodic protection of coated and uncoated ground legs.

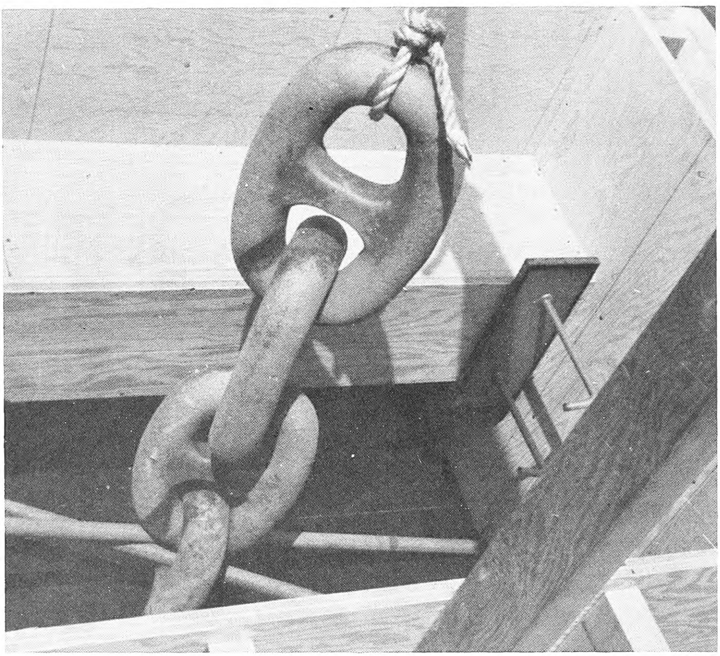

Figure 5. Chain links in wooden form ready for casting of concrete sinker block.

Installation. The entire mooring complex was placed on the deck of a floating crane in position for laying (Figure 6). The two ground cables connected to the control head in each sinker block were coiled and tucked inside the groove in the block (Figure 7) to protect them from damage during laying operations. A 75-foot length of similar cable was welded to the second A-link from the ground ring, and a 50-foot length of cable was welded to the second A-link from the anchor of each ground leg. These cables were also coiled tightly and tied in place prior to laying operations. A tight mooring was carefully placed in its assigned location in the San Diego Bay.

Three days after the mooring had been layed, the cathodic protection units on the ground legs were connected for service. Two of the four sinker blocks were found by divers to be lying on the side containing the unit. The blocks were righted, and the ground cables on each unit were uncoiled and connected as follows. The free end of the cable from the control head and the free end of the cable attached near the ground ring were brought to the surface. The lugs on each end were joined with a nut and bolt and were silver-soldered together to insure electrical continuity. The joined cables were then allowed to sink to the bottom of the bay. The second cable on the control head and the cable attached near the anchor were similarily joined to give the electrical circuitry shown in Figure 1. The riser-chain was then shortened to 23 feet so that the ground ring just touched bottom at mean lower low water in this 38-foot-depth location.

Another Mark II peg-top riser-chain buoy was coated with the phenolic mastic system used on the cathodically protected buoy to serve as a control for the latter. A foot-square area was sandblasted to white metal on the cone of this buoy for comparison with the similar area on the cathodically protected buoy. The riser-chain and two of the three ground legs were coated with cold-applied coal tar coating MIL-C-18480A; the third leg was allowed to remain bare. The control mooring was then placed in an area of the San Diego Bay adjacent to that of the cathodically protected mooring. Both the cathodically protected mooring and the control mooring received relatively light service from ships during the period of in-service testing described in this report.

Performance. Immediately after laying, the potential of the cathodically protected buoy was –850 mv.* No potential reading was made immediately after connecting the cables on the ground legs and shortening the riser-chain because darkness had long since fallen. Three weeks later, when a potential profile was made of the mooring complex, the buoy potential had fallen to –730 mv.

---

* All potentials reported are with respect to a silver/silver chloride reference half-cell.

Figure 6. Initially designed system prepared for laying.

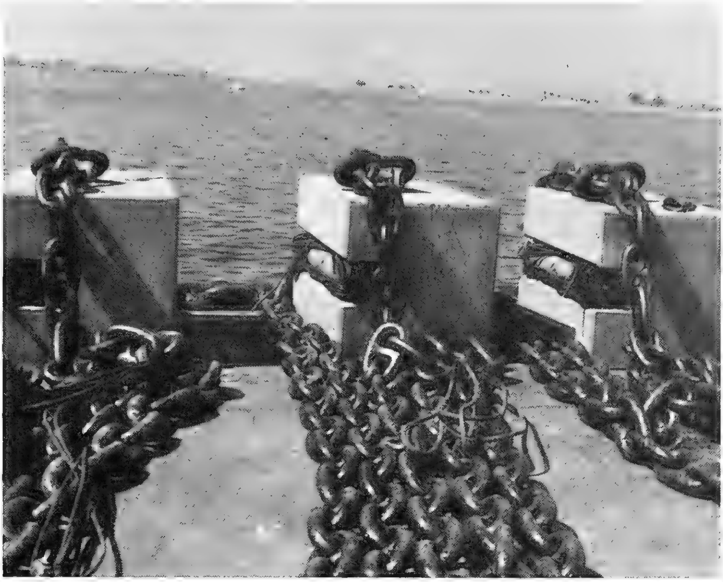

Figure 7. Sinker blocks housing cathodic protection units with coiled cables prior to laying of system.

The potential profile of the cathodically protected mooring was made using a portable field meter and two 50-foot leads. A silver/silver chloride reference half-cell was attached to one of these leads and a steel pick to the other. The instrument was read at the surface while a diver made electrical contacts with the pick at the mooring chain; the half-cell was held 1 foot from the point of contact. The readings received are listed in Table 1.

The potential of the control buoy was found to be –680 mv at the time the potential profile of the cathodically protected buoy was made. The potential of the ground ring was –665 mv, and the potentials 10 feet down the two painted and one bare leg were –675, –690, and –680 mv, respectively.

The control heads of the cathodic protection system were not functioning properly, and the supplier was unable to make the alterations necessary for their proper operation. Thus, it was decided that the system should be modified by replacing the magnesium anodes with ones of zinc which require no control head for regulating the potentials.

Table 1. Potential Profile of Mooring With Magnesium Anodes

Reading No.[a]	Potential (mv) on—				
	Riser-Chain (coated)	Leg 1 (coated)	Leg 2 (bare)	Leg 3 (coated)	Leg 4 (coated)
1	-730[b]	-700[c]	-700[c]	-700[c]	-700[c]
2	-710	-700[d]	-710[d]	-720[d]	-690[d]
3	-710	-670	-710	-710	-700
4	-710	-680	-710	-720	-700
5	-700[c]	-670	-710	-710	-710
6	—	-670	-700	-700	-670
7	—	-670	-690	-700	-660
8	—	-670	-700	-700	-660
9	—	-710	-680	-700	-670
10	—	-710	-690	-700	-700
11	—	-710	-710	-710	-695
12	—	-710	-730	-720	-680
13	—	-720[d]	-730[d]	-710[d]	-670[d]

[a] Readings taken approximately every 10 feet on the riser-chain and every 20 feet on the ground legs.

[b] At buoy.

[c] At ground ring.

[d] At link to which remote ground cable is connected.

Zinc Anodes

Installation of Zinc Anodes. At the time the magnesium anodes were to be replaced with ones of zinc, the buoy potential was -730 mv, the same as when measured 3 weeks earlier. The buoy was lifted out of the water onto the deck of a floating crane. There was considerable fouling, notably tunicates, on both the buoy and the two magnesium anodes. The square of bare steel in the submerged zone of the buoy had a light coat of rust that was easily removed by manual wire brushing.

The magnesium anodes were removed from the buoy with no difficulty because the nuts and studs securing them had very little corrosion. Zinc anodes, each weighing 144 pounds, were installed where the two magnesium anodes had been removed. The remote ground cable was severed at each control head, and two inches of insulation were cut from the ends. The bare ends were placed

inside the steel pipe on which the zinc anode had been cast and were silver-soldered to the pipe (Figure 8). Thus, the control heads were bypassed in the circuitry and served merely as securing brackets. The connections were wrapped with electrical tape, and the buoy was returned to the water,

The magnesium anode on each of the four concrete sinker blocks was similarly replaced with a zinc anode. The magnesium anode and the two ends of the remote ground cables that were severed at the control head were brought to the surface by a diver. The two ends were silver-soldered into the pipe on which the zinc anode had been cast. This unit was then lowered to the sinker block and secured in place.

Performance. Immediately after installation of the zinc anodes on the buoy and sinker blocks, the buoy potential was –865 mv, while halfway down the riser-chain the potential was –830 mv and that on the ground ring was –780 mv. The potential on each of the four A-links, which were near the ground ring, to which the remote ground cables were connected was also –780 mv. This immediate increase in potential over that previously imparted by the magnesium anodes indicates that the control heads used on the original system had not permitted the greater driving force produced by the magnesium anodes (potentials of –1,450 mv were measured on the steel pipes supporting the magnesium anodes) to reach the buoy and ground tackle.

Three months after the zinc anodes were installed in the cathodic protection system, a potential profile was made of the mooring complex. The values received are listed in Table 2, and they indicate that the buoy was receiving full protection, the riser-chain moderate protection, but the round legs insufficient protection. The potential of the control buoy at this time was –710 mv, while that of its ground ring was –715 mv and that of the ground legs averaged –660 mv.

Four months later, the complete mooring was picked up to determine its condition, and tests were made to determine the reasons for the inadequate protection of the ground legs. Before pickup, the buoy had a potential of –830 mv. The underwater portion of the buoy was covered with heavy fouling. There was no fouling on the zinc anodes, but they were covered with a loose, yellow film that was easily removed by high-pressure hosing. The underlying metal was bright and crystalline in appearance, giving no indication of passivation. The square of bare steel on the underwater portion of the buoy was free of corrosion. The coating on the entire riser-chain was in good condition, and no corrosion was in evidence. The ground ring and the adjacent links on the ground legs were also free of corrosion. In contrast, the square of bare steel on the control buoy was pitting, and almost all of the coating had been lost from the riser-chain, which was corroding badly.

Figure 8. Silver soldering of ground cable to steel pipe supporting the zinc anode.

There was, as anticipated, extensive loss of coating and corrosion on the ground legs of the cathodically protected buoy. The two remote ground cables that were attached to Leg 1 had been torn loose, thus accounting for the −1,060-mv potential shown in Table 2 for the anode pipe. This anode looked the same as when it was first placed in service, while those on the other three sinker blocks were in the same condition as the ones on the buoy, indicating that they had been functioning properly.

The resistance in all the ground cables and all the soldered connections was measured using a vacuum tube volt meter. No appreciable resistance was found in any part of the circuitry.

Zinc Anodes With Additional Leads

A test was made to determine the effect on the potential profile by adding additional leads from the anodes to the mooring. On the buoy, a connection was made from the end of the anodes opposite the control head directly to the buoy shell. On the ground legs, two leads were joined from each anode in the sinker block to a link located 6 feet on either side of the block. The entire mooring was reinstalled in the Bay as tightly as possible.

Table 2. Potential Profile of Mooring With Zinc Anodes

Reading No.[a]	Potential (mv) on—				
	Riser-Chain (coated)	Leg 1 (coated)	Leg 2 (bare)	Leg 3 (coated)	Leg 4 (coated)
1	-830[b]	-750[c]	-770[c]	-760[c]	-730[c]
2	-800	-730	-690	-780	-730
3	-800	-700	-690	-700	-670
4	-800	-685	-690	-690	-660
5	-800[d]	-690	-680	-700	-650
6	—	-670	-685	-680	-655
7	—	-680	-680	-690	-655
8	—	-660	-690	-675	-660
9	—	-710	-685	-680	-665
10	—	-1,060[e]	-885[e]	-890[e]	-840[e]
11	—	-710	-670	-690	-685
12	—	-715	-680	-700	-710
13	—	-735	-690	-810	-730
14	—	-775[c]	-810[c]	-810[c]	-730[c]

[a] Readings taken approximately every 10 feet on the riser-chain and every 20 feet on the ground legs.

[b] At buoy.

[c] At link to which remote ground cable is connected.

[d] At ground ring.

[e] At pipe on which anode was cast.

Immediately after positioning the mooring, the buoy potential was -740 mv. On the next day a potential profile was made of the mooring complex, and the values received are listed in Table 3. They indicate that more current was flowing because of the additional leads, but that the ground legs were still receiving insufficient protection. The potential at the anode pipe on Leg 1 had fallen to approximately the same level as that on the other three legs, indicating that it was now functioning properly after being repaired.

The lower potential value on the buoy (-740 mv) after the addition of the extra leads was attributed by the supplier of the zinc anodes to the laying of a tighter mooring; this allowed greater amounts of current to flow down the riser-chain, protecting the ground legs. In order to test this hypothesis, potential values were measured down the riser-chain of another test buoy

in the San Diego Bay that had a single zinc anode and a relatively slack riser-chain. These values were found to be -980 mv on the buoy, -840 mv 4 feet down the chain, and -685 mv halfway down the chain. This indicates that the fall-off in potential is more rapid for a relatively slack chain than for a tighter chain.

It was concluded that the zinc anodes were functioning properly, but there were an insufficient number to produce the desired level of protection. Thus, the cathodic protection design was changed to include a greater number of larger zinc anodes that would be cast on special chain links in order to become an integral part of the ground tackle.

Table 3. Potential Profile of Mooring With Zinc Anodes and Additional Leads

Reading No.[a]	Potential (mv) on—				
	Riser-Chain (coated)	Leg 1 (coated)	Leg 2 (bare)	Leg 3 (coated)	Leg 4 (coated)
1	-840[b]	-690[c]	-670[c]	-680[c]	-690[c]
2	-850[b]	-640	-655	-655	-640
3	-740[d]	-640	-675	-650	-640
4	-720	-635	-675	-655	-635
5	-710	-650	-660	-660	-650
6	-690	-640	-660	-645	-640
7	-670[e]	-655	-655	-640	-675
8	—	-675	-660	-650	-680
9	—	-700	-695	-660	-700
10	—	-710[c]	-695[c]	-730[c]	-710[c]
11	—	-750[b]	-730[b]	-805[b]	-750[b]
12	—	-710[c]	-700[c]	-710[c]	-710[c]
13	—	-700	-690	-705	-700
14	—	-690	-690	-700	-700
15	—	-690	-685	-700	-690
16	—	-675	-685	-700	-675
17	—	-670[c]	-695[c]	-705[c]	-670[c]

[a] Readings taken approximately every 10 feet on the riser-chain and every 20 feet on the ground legs.

[b] At pipe on which anode was cast.

[c] At link to which remote ground cable is connected.

[d] At buoy.

[e] At ground leg.

Specialized Zinc Anodes

The anodes in the new cathodic protection system had to be specially manufactured. They were prepared by casting SA-3 zinc alloy on a 2-1/2-inch-thick, 35-inch-long steel link. The zinc casting was 1.8 feet long, was approximately 6.6 ft^2 in total surface area, and had a trapezoidal cross section. The entire anode weighed approximately 485 pounds (Figure 9).

The design of the cathodic protection system is shown in Figure 10. Two of the smaller zinc anodes (approximately 144 pounds) used in the previous study on buoys were located in the sea chests on opposite sides of the buoy cone. Three of the special anodes were inserted in each leg, and one was inserted in the riser-chain approximately 3 feet above the ground ring. The anodes were secured into the recoated ground tackle using standard detachable links. With this method no place on the chain was farther than 45 feet from an anode.

Figure 9. Specially cast zinc anode on chain link.

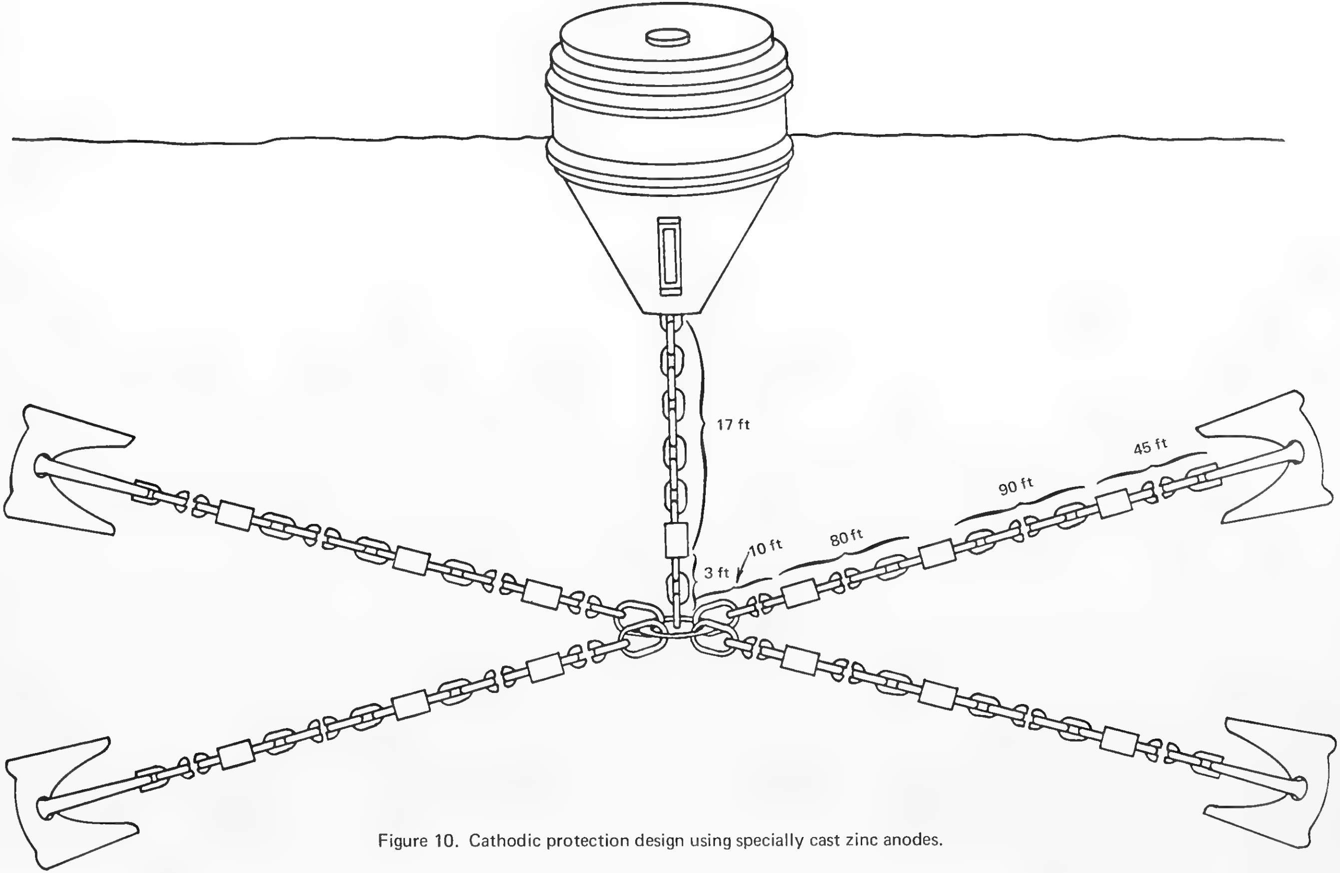

Figure 10. Cathodic protection design using specially cast zinc anodes.

The entire mooring complex was layed out on the deck of a floating crane (Figure 11) and later carefully lowered into service to avoid abrasion or impact damage to the anodes.

Immediately after placement of the mooring, the potential of the buoy was found to be -920 mv. On the following day a potential profile was made of the mooring, and the readings received are listed in Table 4. Another potential profile was made 3 months later, after the chains had had considerable time to erode the recently applied coal tar coating by movement during tidal change. These later readings are listed in Table 5.

The results of Tables 4 and 5 indicate that the zinc anodes were working properly and that some of the ground tackle was being protected. They also indicate that a lack of electrical continuity on other parts of the ground legs prevented complete protection there.

In order to determine ways to obtain better electrical continuity between chain links, two of the ground legs were slightly modified 8 months after the readings of Table 5 were made. One leg was removed from the water, and those portions of the chain links that come into contact with each other were sandblasted using the portable sandblast equipment aboard a floating crane. This ground leg was then returned to its normal location underwater. A second ground leg was removed from the water and layed out on the deck of the floating crane. Three 3/4-inch-diameter galvanized steel cables were woven back and forth through every sixth link. One cable extended from the A-link nearest the anchor to the A-link nearest the zinc anode 45 feet away. The other two cables extended between the zinc anodes which were 90 and 80 feet apart. The ends of each cable were silver-soldered to the A-link nearest the anode (Figure 12), and the cable was also silver-soldered approximately every 9 feet to the chain. Sufficient slack was allowed between fixed positions so that there was no strain on the cable. This ground leg was then returned to its normal position with no difficulty.

While the ground legs were out of the water, each anode was examined. There was no sign of passivation, and plenty of zinc remained for further use. Zinc losses occurred in irregular pits rather than in a uniform manner.

A potential profile was made on the entire mooring 1 week after the two ground legs had been modified, and the readings are listed in Table 6. They indicate that, while the sandblasting had little effect, the cables provided the necessary continuity for complete cathodic protection. Because of the very promising results with the cable-modified leg, the cathodic protection design was further modified to include cables for all of the ground legs.

Figure 11. Ground tackle with specially cast anodes on deck of floating crane rigged for laying.

Table 4. Potential Profile of Mooring With Specialized Zinc Anodes 1 Day After Installation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-935[b]	-860[c]	-860[c]	-860[c]	-860[c]
2	-905	-890	-895	-900	-880
3	-910	-950[d]	-990[d]	-1,020[d]	-990[d]
4	-1,010[d]	-850	-915	-670	-670
5	-860[c]	-720	-910	-670	-670
6	—	-720	-910	-680	-670
7	—	-685	-700	-695	-670
8	—	-690	-710	-695	-670
9	—	-680	-710	-705	-740
10	—	-845	-715	-710	-755
11	—	-1,020[d]	-1,035[d]	-1,065[d]	-1,000[d]
12	—	-660	-940	-710	-665
13	—	-665	-925	-705	-660
14	—	-670	-650	-690	-665
15	—	-675	-650	-690	-665
16	—	-675	-650	-690	-670
17	—	-670	-655	-700	-675
18	—	-675	-670	-710	-675
19	—	-675	-710	-720	-690
20	—	-865	-680	-750	-840
21	—	-975[d]	-1,070[d]	-1,055[d]	-980[d]
22	—	-770	-700	-690	-840
23	—	-645	-700	-700	-835
24	—	-645	-690	-700	-830
25	—	-650	-690	-700	-825
26	—	-645	-690	-700	-770
27	—	-635[e]	-710[e]	-700[e]	-610[e]

[a] Readings taken approximately every 10 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Table 5. Potential Profile of Mooring With Specialized Zinc Anodes 3 Months After Installation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-960[b]	-905[c]	-905[c]	-905[c]	-905[c]
2	-940	-920	-890	-940	-935
3	-940	-940[d]	-950[d]	-975[d]	-990[d]
4	-980[d]	-920	-905	-935	-935
5	-905[c]	-860	-895	-930	-930
6	—	-700	-900	-695	-925
7	—	-690	-900	-690	-915
8	—	-690	-880	-680	-915
9	—	-685	-695	-685	-940
10	—	-935	-735	-750	-950
11	—	-1,030[d]	-990[d]	-1,050[d]	-995[d]
12	—	-680	-950	-685	-680
13	—	-680	-950	-680	-660
14	—	-695	-880	-680	-660
15	—	-690	-650	-675	-675
16	—	-685	-650	-670	-680
17	—	-685	-650	-675	-685
18	—	-675	-645	-680	-685
19	—	-735	-645	-690	-700
20	—	-750	-645	-820	-870
21	—	-990[d]	-1,015[d]	-1,015[d]	-950[d]
22	—	-910	-850	-675	-880
23	—	-690	-720	-680	-850
24	—	-670	-700	-675	-840
25	—	-670	-680	-670	-860
26	—	-675	-645	-655	-845
27	—	-670[e]	-645[e]	-660[e]	-725[e]

[a] Readings taken approximately every 10 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Table 6. Potential Profile of Mooring With Specialized Zinc Anodes and Two Modified Legs

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1[b]	Leg 2	Leg 3	Leg 4[c]
1	-960[d]	-895[e]	-895[e]	-895[e]	-895[e]
2	-920	-960	-900	-980	-950
3	-915	-1,000[f]	-980[f]	-1,020[f]	-1,000[f]
4	-960[f]	-735	-900	-980	-965
5	-890[e]	-735	-900	-730	-965
6	—	-735	-850	-690	-955
7	—	-735	-850	-690	-935
8	—	-740	-790	-690	-940
9	—	-740	-695	-690	-935
10	—	-740	-720	-970	-935
11	—	-1,060[f]	-1,055[f]	-1,050[f]	-970[f]
12	—	-750	-680	-730	-930
13	—	-745	-660	-690	-915
14	—	-745	-655	-680	-915
15	—	-730	-655	-680	-920
16	—	-725	-660	-680	-935
17	—	-725	-660	-675	-920
18	—	-730	-660	-675	-920
19	—	-735	-655	-675	-920
20	—	-730	-670	-700	-915
21	—	-1,035[f]	-1,040[f]	-1,050[f]	-980[f]
22	—	-730	-650	-680	-915
23	—	-730	-650	-675	-900
24	—	-720	-650	-670	-900
25	—	-720	-650	-650	-895
26	—	-720	-650	-650	-880
27	—	-720[g]	-650[g]	-650[g]	-800[g]

[a] Readings taken approximately every 10 feet.

[b] Sandblasted leg.

[c] Leg with attached cable.

[d] At buoy.

[e] At ground ring.

[f] At link on which anode was cast.

[g] At anchor.

Figure 12. Cable silver-soldered to chain link.

Specialized Zinc Anodes With Steel Cables

Repairs and Fabrication. The modification of the cathodically protected mooring was accomplished when both it and the unprotected control mooring were scheduled for their periodic removal and rehabilitation ashore.

The total cost for rehabilitation of the control mooring amounted to $4,617 of which $2,000 was for pickup and installation and $2,617 was for repairs. The unprotected ground ring assembly was loose, and all rivets needed replacing. The pear links were badly pitted, and the thickness was reduced in places to 1-1/2 inches (a loss of 40%), necessitating their replacement (Figure 13). The chain thickness for the first five links on all legs had been reduced to about 1-7/8 inches.

The cathodically protected mooring required no repair work, but the ground tackle was recoated by dipping the sandblasted chain into a tank of cold-applied coal tar coating, MIL-C-18480A. The anodes on the ground legs had lost very little zinc while providing the current necessary for cathodic protection. Those nearest the ground ring had generally lost slightly more zinc, because higher potentials had been provided in these areas. The two smaller anodes located in the sea chests built into the buoy cone also had lost relatively little zinc.

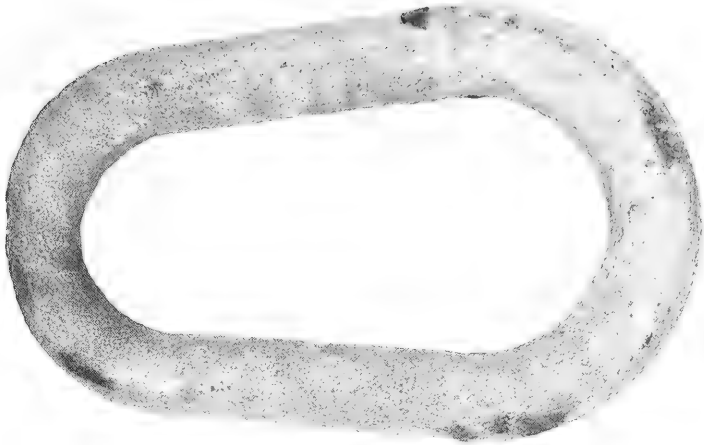

Figure 13. Pear link from control mooring showing pitting and greatly reduced thickness.

The modified cathodic protection design is shown in Figure 14. A single length of galvanized steel cable was loosely woven back and forth through every sixth link of each leg and was joined to the chain approximately every 5 feet. On two of the legs the joints were accomplished by silver soldering, and on the other they were accomplished with pipe clamps (Figure 15). The advantages of joining with pipe clamps were (1) it was faster, (2) it did not require the services of a welder, and (3) it did not require heating which might slightly decrease the strength of the heated link. The clamps were snapped into position and were then further tightened with a screwdriver. One pipe clamp was installed by a diver at the time of a later inspection to demonstrate that securing the cable underwater presented no real difficulty.

As shown in Figure 14, Legs 1 and 3 were of 2-1/4-inch cast steel chain with 3/4-inch galvanized steel cables clamped to them; Legs 2 and 4 were of 2-1/4-inch die lock chain with 3/4-inch galvanized steel cables welded to them. The cable on each leg was terminated approximately six links from the jew's harp of the anchor, rather than at the A-link nearest the anchor as in the previous test, to minimize current loss to the anchor. Thus, full protection of the chain was desired rather than partial or complete protection of the anchor.

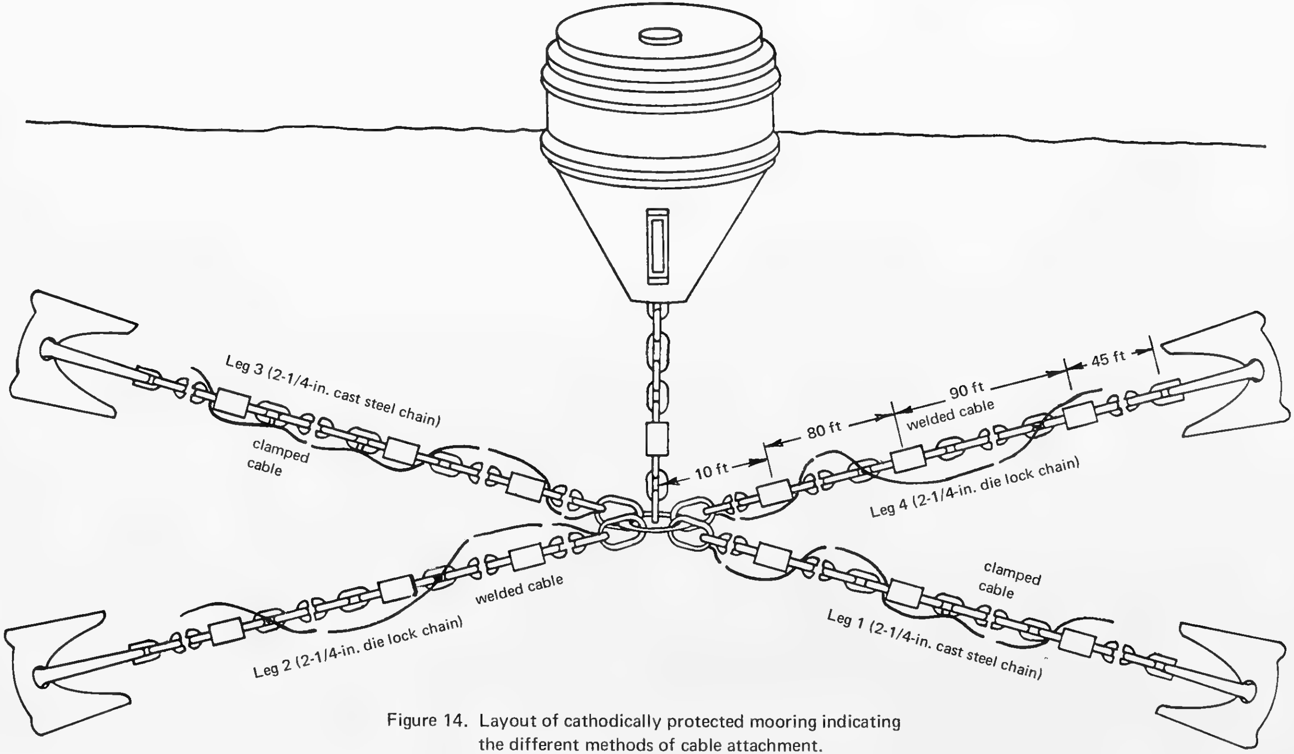

Figure 14. Layout of cathodically protected mooring indicating the different methods of cable attachment.

Figure 15. Cable clamped to chain link and a clamp shown prior to use.

Performance. A potential profile of the modified mooring was made approximately 3 weeks after the mooring was laid, giving the data listed in Table 7. It can be seen from these data that all readings were well above the desired minimum level of –850 mv and most were above –1,000 mv. Two of the four anchors were also receiving cathodic protection despite the attempt to prolong anode life by avoiding this.

Additional potential profiles were prepared 4, 10, and 13 months after installation of the modified mooring. These are shown in Tables 8, 9, and 10, respectively. From these tables it can be seen that the underwater portion of the buoy, the riser-chain, and all four ground legs were receiving full protection from corrosion. All potentials were well above the desired minimum level of –850 mv, and almost all were above –900 mv. In addition, two of the four anchors were receiving full protection much of the time, despite attempts to avoid it.

Table 7. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 3 Weeks After Installation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-1,050[b]	-1,060[c]	-1,060[c]	-1,060[c]	-1,060[c]
2	-1,070	-1,050	-1,080	-1,035	-1,040
3	-1,070	-1,055[d]	-1,100[d]	-1,060[d]	-1,055[d]
4	-1,070[d]	-1,045	-1,080	-1,050	-1,050
5	-1,060[c]	-1,045	-1,040	-1,040	-1,045
6	—	-1,040	-1,040	-1,030	-1,035
7	—	-1,040	-1,020	-1,030	-1,035
8	—	-1,060	-1,010	-920	-1,040
9	—	-1,040	-1,040	-1,050	-1,045
10	—	-1,035	-1,040	-1,020	-1,050
11	—	-1,070[d]	-1,050[d]	-1,050[d]	-1,050[d]
12	—	-1,050	-1,030	-1,040	-1,025
13	—	-990	-1,020	-1,040	-1,030
14	—	-1,020	-1,020	-1,030	-1,030
15	—	-1,020	-1,020	-1,040	-1,025
16	—	-1,050	-1,020	-1,040	-1,025
17	—	-1,060	-1,030	-920	-1,020
18	—	-1,050	-900	-1,050	-1,025
19	—	-1,050	-1,020	-1,040	-1,020
20	—	-1,050	-1,030	-920	-1,030
21	—	-1,060[d]	-1,060[d]	-1,050[d]	-1,050[d]
22	—	-1,050	-1,010	-1,020	-1,020
23	—	-1,050	-1,010	-1,040	-1,020
24	—	-1,060	-1,010	-1,020	-1,015
25	—	-1,050	-1,010	-1,020	-1,015
26	—	-1,040	-1,010	-1,020	-1,015
27	—	-630[e]	-820[e]	-680[e]	-910[e]

[a] Readings taken approximately every 10 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Table 8. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 4 Months After Installation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-960[b]	-970[c]	-970[c]	-965[c]	-975[c]
2	-950	-1,000	-1,000	-970	-980
3	-960	-1,020[d]	-1,020[d]	-990[d]	-1,000[d]
4	-980[d]	-970	-1,000	-960	-975
5	-970[c]	-970	-980	-955	-960
6	—	-960	-980	-960	-950
7	—	-980	-965	-965	-955
8	—	-980	-930	-970	-970
9	—	-960	-950	-965	-970
10	—	-1,000	-980	-980	-1,010
11	—	-1,020[d]	-1,000[d]	-1,000[d]	-1,020[d]
12	—	-980	-1,000	-960	-945
13	—	-975	-990	-965	-965
14	—	-980	-980	-965	-965
15	—	-985	-960	-965	-975
16	—	-980	-920	-965	-940
17	—	-970	-980	-960	-930
18	—	-965	-985	-965	-940
19	—	-960	-980	-960	-950
20	—	-980	-920	-960	-945
21	—	-1,020[d]	-1,020[d]	-1,000[d]	-1,005[d]
22	—	-1,000	-1,000	-965	-925
23	—	-960	-960	-965	-920
24	—	-955	-950	-960	-910
25	—	-965	-960	-950	-880
26	—	-950	-945	-950	-880
27	—	-650[e]	-720[e]	-720[e]	-740[e]

[a] Potentials recorded approximately every 10 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Table 9. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 10 Months After Installation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-940[b]	-940[c]	-940[c]	-940[c]	-940[c]
2	-945	-960	-940	-945	-945
3	-950	-990[d]	-990[d]	-980[d]	-975[d]
4	-970[d]	-935	-940	-950	-940
5	-945[c]	-935	-940	-945	-935
6	—	-935	-935	-940	-935
7	—	-935	-930	-940	-935
8	—	-935	-935	-940	-930
9	—	-935	-930	-940	-930
10	—	-925	-935	-940	-930
11	—	-975[d]	-990[d]	-985[d]	-980[d]
12	—	-895	-925	-940	-925
13	—	-925	-930	-940	-920
14	—	-925	-925	-920	-915
15	—	-925	-925	-940	-920
16	—	-920	-920	-935	-910
17	—	-920	-920	-935	-910
18	—	-915	-920	-935	-910
19	—	-920	-920	-935	-910
20	—	-910	-920	-930	-910
21	—	-975[d]	-990[d]	-970[d]	-965[d]
22	—	-930	-920	-930	-905
23	—	-925	-910	-930	-900
24	—	-925	-905	-930	-900
25	—	-925	-905	-930	-890
26	—	-925	-900	-930	-880
27	—	-660[e]	-870[e]	-670[e]	-850[e]

[a] Readings taken approximately every 10 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Table 10. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 13 Months After Installation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-960[b]	-940[c]	-950[c]	-950[c]	-940[c]
2	-950	-980	-950	-960	-950
3	-950	-1,000[d]	-990[d]	-980[d]	-975[d]
4	-990[d]	-935	-935	-935	-930
5	-945[c]	-930	-935	-935	-920
6	—	-930	-930	-925	-925
7	—	-930	-925	-915	-920
8	—	-930	-930	-915	-920
9	—	-930	-925	-910	-915
10	—	-940	-925	-930	-930
11	—	-990[d]	-990[d]	-990[d]	-980[d]
12	—	-940	-940	-935	-925
13	—	-935	-935	-930	-925
14	—	-930	-930	-930	-920
15	—	-935	-920	-930	-915
16	—	-935	-920	-920	-920
17	—	-935	-920	-910	-910
18	—	-925	-920	-920	-910
19	—	-920	-925	-930	-905
20	—	-920	-925	-930	-905
21	—	-1,000[d]	-990[d]	-980[d]	-995[d]
22	—	-950	-920	-935	-920
23	—	-940	-910	-925	-905
24	—	-935	-910	-920	-910
25	—	-940	-910	-920	-900
26	—	-940	-910	-910	-900
27	—	-665[e]	-875[e]	-695[e]	-850[e]

[a] Readings taken approximately every 10 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Relocation of Mooring. After 13 months of service to the Fleet, the cathodically protected mooring was removed, examined, and relocated. This move permitted testing in a different type of environment. The new location had a muddy bottom quite different from the sandy, rocky bottom area where the mooring was first installed. In addition to bottom differences, tidal currents would be appreciably less. Before relocation, divers inspected a mooring in this area and determined that potential readings could be taken on the ground legs covered with mud without too much difficulty.

At the time of relocation the mooring buoy was in excellent condition both above and below water. The square area below the waterline of the buoy, which had been sandblasted to bare steel at the start of the test program, had a thin layer of tightly adhering rust and some fouling organisms but no pitting or other sign of significant corrosion damage. There were irregular losses of zinc from the two anodes located in the sea chests in the buoy, but plenty of zinc remained for additional service.

The mooring chains were also in excellent condition. The mooring crew remarked that they looked as good as the day they were installed. Not only was corrosion negligible, but the coating was in good condition. The anodes had a loose, yellowish film but no fouling on them. They showed no signs of passivation, such as was found by Peterson and Waldron[15] on zinc anodes in the San Diego Bay. It was not practical to weigh the anodes, but based on a visual inspection it was estimated that they would have an effective service life of at least 8 years. The cables that were silver-soldered to two of the ground legs had suffered localized damage at two points. Apparently the cables were damaged in these areas by the heat from the torch used in silver soldering and were later pulled apart during handling, either in laying or picking up the mooring. Before relocating the mooring, repairs were made by silver soldering the broken cables and then clamping them to the chains with pipe clamps. In a few places where the silver-soldered joint between the cable and chain had been broken without damage to the cable, repairs were also made by clamping the cable back into position. No apparent damage to the pipe clamps used on the other two ground legs could be detected.

The first attempt at obtaining a potential profile at the new site was made about 4 months after relocation. At that time Legs 3 and 4 were under about 1 foot of mud, and Legs 1 and 2 were under about 2 to 3 feet of mud. A rather strong wind and the erratic operation of one of the engines of the diving boat further complicated the measurement of potentials. It was difficult to obtain precise readings, because the diver could not maintain contact with the chain for a prolonged period of time. Two of the anodes on one of the legs were buried in the mud and could not be located by the diver. As a

result, only the partial potential profile listed in Table 11 was achieved. All measurements were well above the desired minimum of -850 mv, and all except one were -900 mv or above.

Table 11. Partial Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 4 Months After Relocation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4[b]
1	-960[c]	-905[d]	-905[d]	-905[d]	-905[d]
2	-940	-905	-900	-910	-980
3	-940	-950[e]	-960[e]	-970[e]	-910
4	-1,005[e]	-900	-910	-920	-910
5	-905[d]	-900	-910	-920	-920
6	–	-900	-915	-920	-920
7	–	-900[f]	-915	-920	-920
8	–	–	-920	-920	-920
9	–	–	-920	-920	-920
10	–	–	-960[e]	-975[e]	-925
11	–	–	-910	-910	-925
12	–	–	-910	-910	-920
13	–	–	-900	-920	-920
14	–	–	-900	-920	-920
15	–	–	-900	-915	-920
16	–	–	-880	-915	-920
17	–	–	-960[e,g]	-960[e]	-980[e]
18	–	–	–	-905	-930
19	–	–	–	-905	-925
20	–	–	–	-900	-920
21	–	–	–	-880[h]	-660[h]

[a] Readings taken about every 10 to 20 feet.

[b] Two anodes in the mud could not be located.

[c] At buoy.

[d] At ground ring.

[e] At link on which anode was cast.

[f] Leg lost in mud; unable to repeat measurement because of engine failure.

[g] Measurements discontinued because of engine failure.

[h] At anchor.

About 9 months after the relocation of the mooring, another potential profile was made. A new, more easily handled diving boat was used, and there was no appreciable wind. All four ground legs were covered with about 1 foot of mud, and one anode on Leg 4 could not be located. However, it was much easier to measure the potentials that are recorded in Table 12. All the potentials measured were still well above -850 mv, but those on Leg 2 were noticeably lower than those on the other legs. This could be due in part to a sluggishness of the meter and the inability of the diver to maintain contact with the chain for an extended period of time. One of the anchors was receiving full protection from corrosion, one partial protection, and two no appreciable protection. It is interesting that the anchor on Leg 3 that was receiving full protection after 4 months was receiving no protection after 9 months.

The potential profile of the mooring was again taken 15 months after relocation. It was possible to measure the potentials at all key points of the mooring. These measurements are recorded in Table 13. Again all of the measurements were well above the desired minimum of -850 mv.

This time Leg 1 had very slightly lower readings than the other three legs. Two of the anchors were receiving partial protection from corrosion and two were receiving no appreciable protection.

Eleven months after relocation of the cathodically protected mooring, the buoy was lifted from the water for the annual inspection specified in BUDOCKS Instruction 11153.4B. At that time the buoy was in excellent condition except for extensive marine borer damage to the lower wooden fender. There was very little corrosion above water (a few pinpoint rust spots) and none below. The riser-chain showed no deterioration, and the paint was still intact. A routine thickness measurement with a pair of calipers revealed no reduction in chain thickness but a slight increase due to the thick paint. Both the buoy and the riser-chain had medium to heavy marine fouling typical of other moorings in the area. Tunicates, barnacles, and green algae were the most typical organisms present. These were removed by high-pressure hosing with seawater before the inspection.

The square area below the waterline of the buoy, which had been sandblasted to bare steel at the start of the test program in order to give a better indication of the cathodic protection of exposed steel, was covered with fouling organisms and a black film, but it had no pitting or other signs of active corrosion.

The surfaces of the two anodes in the sea chests in the buoy were covered with a loose, yellowish film, but under this film the zinc metal was bright and irregularly pitted indicating satisfactory performance. More than two-thirds of the original zinc remained on each anode. The diver reported that the anodes on the ground legs were in a similar condition.

Table 12. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 9 Months After Relocation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-940[b]	-890[c]	-890[c]	-890[c]	-890[c]
2	-920	-890	-890	-890	-890
3	-920	-985[d]	-990[d]	-980[d]	-990[d]
4	-970[d]	-930	-920	-930	-920
5	-890[c]	-930	-910	-920	-920
6	–	-925	-915	-930	-920
7	–	-920	-910	-930	-930
8	–	-920	-910	-935	-930
9	–	-930	-910	-935	-935
10	–	-985[d]	-970[d]	-980[d]	-955
11	–	-930	-910	-940	-935
12	–	-920	-880	-940	-935
13	–	-915	-875	-940	-920
14	–	-915	-875	-935	-930
15	–	-915	-885	-920	-930
16	–	-915	-885	-940	-940
17	–	-990[d]	-970[d]	-1,020[d]	-1,000[d]
18	–	-910	-885	-945	-930
19	–	-910	-970	-940	-930
20	–	-900	-870	-940	-930
21	–	-870[e]	-720[e]	-665[e]	-645[e]

[a] Readings taken approximately every 10 to 20 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Twenty-two months after relocation of the cathodically protected mooring, another potential profile was taken. This is shown in Table 14. Again, all readings were above the desired minimum level (–850 mv), and also all readings on the chain were above –900 mv. Three of the four anchors were also receiving appreciable cathodic protection at this time.

Table 13. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 15 Months After Relocation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-955[b]	-880[c]	-880[c]	-880[c]	-880[c]
2	-980	-870	-880	-880	-890
3	-980	-995[d]	-980[d]	-985[d]	-990[d]
4	-980[d]	-920	-920	-930	-920
5	-880[c]	-910	-920	-925	-915
6	—	-900	-920	-920	-915
7	—	-895	-920	-920	-915
8	—	-900	-920	-910	-920
9	—	-905	-930	-920	-925
10	—	-970[d]	-980[d]	-990[d]	-965[d]
11	—	-905	-925	-910	-920
12	—	-895	-920	-920	-930
13	—	-900	-920	-905	-930
14	—	-895	-920	-915	-930
15	—	-895	-920	-920	-930
16	—	-900	-920	-920	-930
17	—	-960[d]	-970[d]	-985[d]	-995[d]
18	—	-900	-920	-905	-930
19	—	-895	-910	-895	-935
20	—	-885	-905	-885	-910
21	—	-690[e]	-720[e]	-770[e]	-655[e]

[a] Readings taken approximately every 10 to 20 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

Twenty-three months after relocation of the cathodically protected mooring, the buoy was lifted from the water for its annual inspection. The buoy and the entire riser-chain was hosed with seawater (Figure 16) to remove the attached fouling organisms. The buoy had lost about half of its lower fender from marine borer attack. There was very little coating damage

(mostly from abrasion) and no detectable rusting of steel below water except for the square of exposed steel that had a hard tight film of rust but no pitting or active corrosion. Rather heavy marine fouling had accumulated since the buoy was washed 1 year earlier. Fouling included tunicates, barnacles, green algae, mussels, and tube worms.

Table 14. Potential Profile of Mooring With Specialized Zinc Anodes and Four Cables 22 Months After Relocation

Reading No.[a]	Potential (mv) on—				
	Riser-Chain	Leg 1	Leg 2	Leg 3	Leg 4
1	-965[b]	-870[c]	-880[c]	-875[c]	-875[c]
2	-985	-920	-910	-915	-915
3	-990	-1,010[d]	-980[d]	-990[d]	-985[d]
4	-1,000[d]	-915	-935	-930	-925
5	-930	-915	-930	-925	-930
6	-875[c]	-915	-930	-925	-925
7	—	-910	-930	-930	-930
8	—	-910	-935	-930	-935
9	—	-860	-935	-920	-955
10	—	-965[d]	-985[d]	-960[d]	-995[d]
11	—	-915	-945	-935	-950
12	—	-910	-945	-915	-945
13	—	-910	-940	-915	-945
14	—	-905	-940	-930	-940
15	—	-905	-930	-925	-935
16	—	-905	-935	-930	-940
17	—	-970[d]	-980[d]	-990[d]	-985[d]
18	—	-915	-950	-925	-945
19	—	-900	-945	-920	-940
20	—	-890	-860	-915	-910
21	—	-785[e]	-660[e]	-825[e]	-785[e]

[a] Readings taken approximately every 10 to 20 feet.

[b] At buoy.

[c] At ground ring.

[d] At link on which anode was cast.

[e] At anchor.

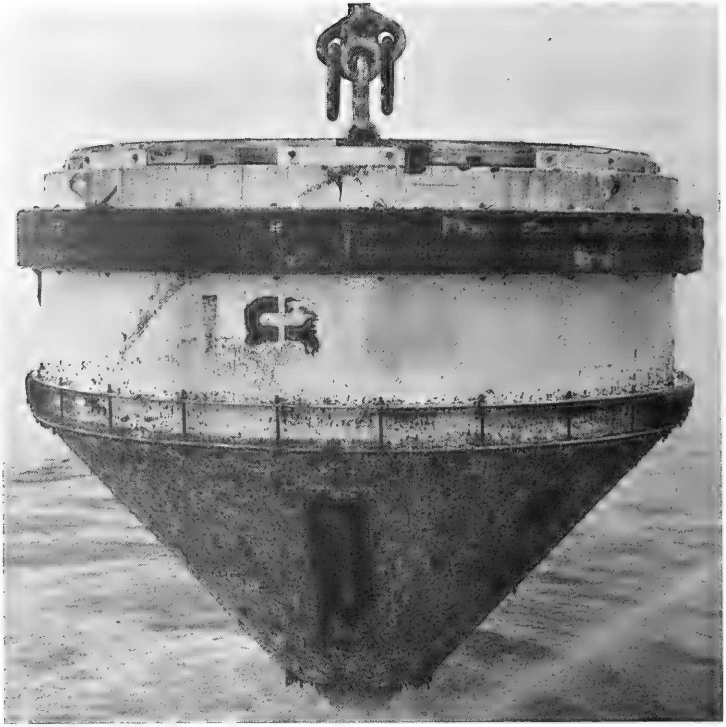

Figure 16. Cleaned buoy 23 months after relocation. Note the lost section of lower fender, the anode in the sea chest, and the square of bare steel.

About one-third of the zinc anodes in the sea chests had been lost, and only about one-tenth of the zinc anodes on the riser-chain (Figure 17) had been lost. The divers who assisted in measuring the potentials indicated that the anodes on the ground legs were in a similar condition.

The riser-chain and ground ring assembly were in excellent condition (Figure 17) with no apparent corrosion. The chain diameter remained at 2-1/2 inches. The ends of the four steel cables that terminated near the ground ring had been pulled loose from their connections to the chains. Welds had been broken from two of the legs, and the cables had been pulled from the cable clamps that remained on the other two legs. This area still had sufficient electrical continuity for complete cathodic protection.

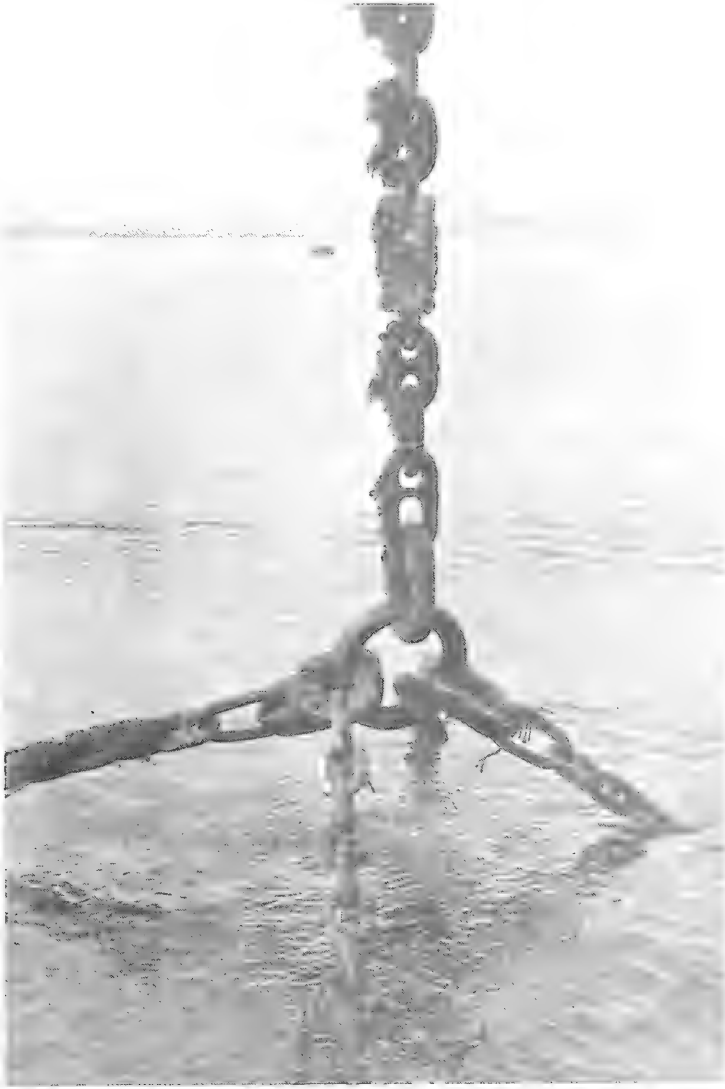

Figure 17. Ground ring assembly and riser-chain with anode 23 months after relocation.

DISCUSSION

The cathodic protection system with the specially cast zinc anodes and steel cables woven through the ground tackle has provided complete protection from corrosion to the underwater portion of the buoy and to all its mooring chains for over 3-1/2 years. The appearance and present size of the anodes indicate that such protection should continue for at least twice this time. In an earlier work,[13] a single 142-pound zinc anode protected the underwater portion of a Mark II peg-top buoy and a portion of the riser-chain for 3-1/2 years. The proof of complete protection of steel from corrosion includes: (1) periodic potential profiles of the complete mooring, (2) appearance of the exposed steel, (3) condition of the protective coating on the chain, and (4) constancy of chain diameter measurements.

The electrical potential profiles changed slightly with each measurement but continued to remain well above the desired minimum level of -850 mv at all times. These changes are attributed to tightening and slacking of the chain by daily tides and by moored ships. The tight portions of the chain near the buoy and ground ring had relatively good electrical continuity, but the portions of the ground legs with relatively little motion needed the steel cables that were woven through them to obtain the electrical continuity required for distribution of the cathodic protection. Even the steel anchors received periodic cathodic protection despite an attempt to prevent this. (Anchor weight losses by corrosion are relatively small and have little effect on holding power.) The cathodic protection system performed well both on a rocky, sandy bottom and on a muddy bottom. The anaerobic microorganisms in the bottom mud did not cause passivation of the zinc anodes.

The square of bare steel exposed on the underwater portion of the buoy had only the passive film of iron oxide associated with cathodic protection. The mooring crew remarked that the ground ring assembly looked as good as when it was first placed into service. This was surprising to them, since the usual losses of metal and resulting reductions in diameter had been attributed by them to wear.

The soft coal tar coating on the chains was in good condition, although there was barnacle penetration on the upper riser-chain. This coating is rapidly undercut by rust on unprotected chain and is in poor condition within 1 year. The good condition of the coating on the protected mooring, in turn, greatly reduced the electrical current needed for cathodic protection.

The control mooring installed at the beginning of the test was removed after 31 months of service. It required extensive and costly rehabilitation before it could be reused by the Fleet.

ANALYSIS OF MAINTENANCE AND REPLACEMENT COSTS

It is difficult to obtain cost data on the purchase and maintenance of Fleet moorings over an extended period of time. Also the maintenance procedures and schedules vary greatly at different naval activities. Cost data for the removal, overhaul, and replacement of six different moorings were provided by Public Works Center, San Diego. These moorings are described in Table 15. From this table it can be seen that the relative costs associated with the rehabilitation of buoys and their chains vary from 50:50 for a three-legged Class D mooring to 30:70 for a 7- or 8-legged Class BB mooring.

Table 15. Description of Moorings Used in Cost Analysis

Mooring No.	Mooring Class	Number of Legs	Percent of Rehabilitation Cost		Holding Power (lb)	Type of Ships Moored
			Buoy	Chain		
BM16	D	3	50	50	75,000	barges and LSTs
16	B	4	40	60	125,000	cruisers and destroyers
34	BB	7	30	70	250,000	cruisers and destroyers
35	BB	8	30	70	250,000	cruisers and destroyers
36	BB	8	30	70	250,000	cruisers and destroyers
37	BB	7	30	70	250,000	cruisers and destroyers

The work centers performing the various phases of the work are listed in Table 16. Sandblasting the metal for painting was done by Work Center 540 (General Support Shop). Both rigging and diving services fall under Work Center 728, but this number will refer only to rigging service unless otherwise specified.

Tables 17 through 21 list the Planning and Estimating Branch estimates for work scheduled for moorings BM16, 16, 34, 35 and 36, and 37, respectively. The work on each mooring was accomplished at different times; therefore, these tables cannot be compared to each other without adjusting for cost charges with time. The tables are included to indicate only the relative costs for each phase

of the work. Table 22 summarizes the labor, material, and other (mostly equipment rental) costs associated with the overhaul of these moorings, projected to June 1970. It can be seen from this table that removal, overhaul, and reinstallation costs for the moorings were about 20%, 35%, and 45%, respectively, of the total rehabilitation costs. Also, the total cost for rehabilitating a Class BB mooring was almost twice that for a Class D mooring.

Table 16. Identification of Work Center Codes

Code	Work Center
210	Engineering Department; Civil Engineering Division
332	Inspection Division
525	Paint Shop
540	General Support Shop
542	Welding Shop
543	Wharf Building Shop
622	Utilities Shop
700	Transportation Department (Equipment Rental)
722	Automotive Operations
724	Heavy Equipment Operations
728	Rigging Service (also Diving Service)
772	Heavy Equipment Maintenance

A cost comparison (Table 23) for maintaining Fleet moorings with and without cathodic protection was prepared from information in Table 22 and elsewhere. Table 24 lists the assumptions that were made for this comparison. A 30-year period was covered in order to combine the 1-, 3-, 5-, 10-, and 15-year cycles.

The present value, **P***, of each series of nonuniform annual payments, A_i, for **n** years, where payment is made at the beginning of the i^{th} year at rate **r** compounded annually, is given by:

$$P = \sum_{i=0}^{n} \frac{A_i}{(1 + r)^i}$$

*The present value is calculated in addition to the much greater undiscounted value because of the importance of the interest factor related to all governmental spending occurring over time.

Thus, for the unprotected Class BB mooring of Table 23,

$$P = \frac{0}{(1 + 0.05)^0} + \frac{500}{(1 + 0.05)^1} + \frac{500}{(1 + 0.05)^2}$$

$$+ \ldots + \frac{70{,}500}{(1 + 0.05)^{30}} = 99{,}193$$

The equivalent annual payment, **N***, of the present value, **P**, for **n** years at rate **r** is given by:

$$N = P \frac{r(1 + r)^n}{(1 + r)^n - 1}$$

Thus, for the unprotected Class BB mooring of Table 23,

$$N = 99{,}193 \frac{0.05(1 + 0.05)^{30}}{(1 + 0.05)^{30} - 1} = 6{,}453$$

Table 25 indicates that an annual savings of about $2,000 to $4,500, depending upon mooring size and configuration, may be realized in the maintenance and replacement of moorings.

This analysis does not consider the eventual replacement of the buoy. The cathodically protected buoy will not deteriorate appreciably underwater and will deteriorate no faster above water than the unprotected buoy. A better mooring design would appear to be one utilizing a low-maintenance plastic mooring buoy[16-18] in conjunction with cathodically protected ground tackle.

---

* The equivalent annual payment is the uniform amount that, if paid annually throughout the useful life of the project, would equal the present value (discounted) total.

Table 17. Estimated Costs for Overhaul Maintenance of Mooring BM16 (Class D, Three-Legged)

Phase of Work	Work Center	Man-Hours	Cost ($)			
			Labor	Materials	Other[a]	Total
Removal of mooring	700	0	0	0	358	358
	722	2	14	0	0	14
	724	20	151	0	0	151
	728	90	707	0	0	707
	total	112	872	0	358	1,230
Overhaul of mooring	332	4	32	0	0	32
	525	20	160	175	0	335
	540	24	175	116	0	291
	542	8	65	116	0	181
	543	52	433	266	0	699
	700	0	0	0	16	16
	724	20	151	0	0	151
	728	20	157	0	0	157
	total	148	1,173	673	16	1,862
Reinstallation of mooring	210	*b*	*b*	*b*	*b*	*b*
	700	0	0	0	358	358
	722	2	14	0	0	14
	724	28	212	0	0	212
	728	118	928	0	0	928
	total	148	1,154	0	358	1,512
Total work	210	*b*	*b*	*b*	*b*	*b*
	332	4	32	0	0	32
	525	20	160	175	0	335
	540	24	175	116	0	291
	542	8	65	116	0	181
	543	52	433	266	0	699
	700	0	0	0	732	732
	722	4	28	0	0	28
	724	68	514	0	0	514
	728	228	1,792	0	0	1,791
	total	408	3,199	673	732	4,604

[a] Mostly equipment rental costs.

[b] No charge.

Table 18. Estimated Costs for Overhaul Maintenance of Mooring 16 (Class B, Four-Legged)

Phase of Work	Work Center	Man-Hours	Cost ($)			
			Labor	Materials	Other[a]	Total
Removal of mooring	700	0	0	0	410	410
	722	2	13	0	0	13
	724	12	82	0	0	82
	728	90	707	0	0	707
	772	10	80	0	0	80
	total	114	882	0	410	1,292
Overhaul of mooring	332	8	58	0	0	58
	525	20	144	195	0	339
	540	40	266	126	0	392
	542	8	62	0	0	62
	543	60	463	258	0	721
	700	0	0	0	6	6
	724	20	137	0	0	137
	728	20	157	0	0	157
	total	176	1,287	579	6	1,872
Reinstallation of mooring	210	*b*	*b*	*b*	*b*	*b*
	700	0	0	0	579	579
	722	6	38	0	0	38
	724	18	123	0	0	123
	728 (divers)	36	964	34	0	998
	728 (riggers)	118	927	0	0	927
	772	14	113	0	0	113
	total	192	2,165	34	579	2,778
Total work	210	*b*	*b*	*b*	*b*	*b*
	332	8	58	0	0	58
	525	20	144	195	0	339
	540	40	266	126	0	392
	542	8	62	0	0	62
	543	60	463	258	0	721
	700	0	0	0	995	995
	722	8	51	0	0	51
	724	50	342	0	0	342
	728 (divers)	36	964	34	0	998
	728 (riggers)	228	1,791	0	0	1,791
	772	24	193	0	0	193
	total	482	4,334	613	995	5,942

[a] Mostly equipment rental costs.

[b] No charge.

Table 19. Estimated Costs for Overhaul Maintenance of Fleet Mooring 34

Phase of Work	Work Center	Man-Hours	Cost ($)			
			Labor	Materials	Other[a]	Total
Removal of mooring	700	0	0	0	451	451
	722	3	20	0	0	20
	724	15	108	0	0	108
	728	108	789	0	0	789
	772	12	99	0	0	99
	total	138	1,016	0	451	1,467
Overhaul of mooring	332	10	76	0	0	76
	525	20	155	235	0	390
	540	52	349	145	0	494
	542	8	63	0	0	63
	543	60	479	248	0	727
	700	0	0	0	170	170
	724	24	173	0	0	173
	728	24	175	0	0	175
	total	198	1,470	628	170	2,268
Reinstallation of mooring	210	*b*	0	0	0	0
	700	0	0	0	751	751
	722	3	20	0	0	20
	724	21	151	0	0	151
	728 (divers)	63	672	0	0	672
	728 (riggers)	140	1,023	10	0	1,033
	772	17	141	0	0	141
	total	244	2,007	10	751	2,768
Total work	210	*b*	40	0	0	0
	332	10	76	0	0	76
	525	20	155	235	0	390
	540	52	349	145	0	494
	542	8	63	0	0	63
	543	60	479	248	0	727
	700	0	0	0	1,372	1,372
	722	6	40	0	0	40
	724	60	432	0	0	432
	728 (divers)	63	672	0	0	672
	728 (riggers)	272	1,987	10	0	1,997
	772	29	240	0	0	240
	total	580	4,493	638	1,372	6,503

[a] Mostly equipment rental costs.

[b] Information only.

Table 20. Estimated Costs for Overhaul Maintenance of Fleet Moorings 35 and 36

(Cost estimates for both Fleet moorings were identical.)

Phase of Work	Work Center	Man-Hours	Costs ($)			
			Labor	Materials	Other[a]	Total
Removal of mooring	700	0	0	0	446	446
	722	4	27	0	0	27
	724	20	144	0	0	144
	728	108	789	0	0	789
	772	12	99	0	0	99
	total	144	1,059	0	446	1,505
Overhaul of mooring	332	8	61	0	0	61
	525	20	155	352	0	507
	540	56	383	163	0	546
	542	8	63	92	0	155
	543	52	415	125	0	540
	700	0	0	0	149	149
	724	24	173	0	0	173
	728	24	175	0	0	175
	total	192	1,425	732	149	2,306
Reinstallation of mooring	210	*b*	0	0	0	0
	700	0	0	0	964	964
	722	4	27	0	0	27
	724	24	173	0	0	173
	728 (divers)	72	768	0	0	768
	728 (riggers)	212	1,550	0	0	1,550
	772	24	199	0	0	199
	total	336	2,717	0	964	3,681
Telephone removal and installation	622 (removal)	8	63	0	0	63
	622 (installation)	8	63	216	0	279
	total	16	126	216	0	342
Total work	210	*b*	0	0	0	0
	332	8	61	0	0	61
	525	20	155	352	0	507
	540	56	383	163	0	546
	542	8	63	92	0	155
	543	52	415	125	0	540
	622	16	126	216	0	342
	700	0	0	0	1,559	1,559
	722	8	54	0	0	54
	724	68	490	0	0	490
	728 (divers)	344	2,514	0	0	2,514
	728 (riggers)	72	768	0	0	768
	772	36	298	0	0	298
	total	688	5,327	948	1,559	7,834

[a] Mostly equipment rental costs.

[b] Information only.

Table 21. Estimated Costs for Overhaul Maintenance of Fleet Mooring 37

Phase of Work	Work Center	Man-Hours	Costs ($)			
			Labor	Materials	Other[a]	Total
Removal of mooring	700	0	0	0	445	445
	722	3	20	0	0	20
	724	15	108	0	0	108
	728	108	790	0	0	790
	772	12	99	0	0	99
	total	138	1,017	0	445	1,462
Overhaul of mooring	332	10	76	0	0	76
	525	20	155	243	0	398
	540	52	356	145	0	501
	542	8	63	0	0	63
	543	60	479	248	0	727
	700	0	0	0	138	138
	724	24	173	0	0	173
	728	24	175	0	0	175
	total	198	1,477	636	138	2,251
Reinstallation of mooring	210	*b*	0	0	0	0
	700	0	0	0	789	789
	722	3	20	0	0	20
	724	21	151	0	0	151
	728 (divers)	63	672	0	0	672
	728 (riggers)	140	1,023	24	0	1,047
	772	17	141	0	0	141
	total	244	2,007	24	789	2,820
Total work	210	*b*	0	0	0	0
	332	10	76	0	0	76
	525	20	155	243	0	398
	540	52	356	145	0	501
	542	8	63	0	0	63
	543	60	479	248	0	727
	700	0	0	0	1,372	1,372
	722	6	40	0	0	40
	724	60	432	0	0	432
	728 (divers)	63	672	0	0	672
	728 (riggers)	272	1,988	24	0	2,012
	772	29	240	0	0	240
	total	580	4,501	660	1,372	6,533

[a] Mostly equipment rental costs.

[b] Information only.

Table 22. Projected (June 1970) Costs for Overhaul Maintenance of Moorings

Phase of Work	Percent of Total Costs	Mooring No.	Projected Costs ($)			
			Labor	Materials	Other[a]	Total
Removal of mooring	26	BM16	1,005	0	395	1,400
	22	16	1,015	0	450	1,465
	21	34	1,455	0	495	1,950
	19	35	1,455	0	490	1,945
	19	36	1,455	0	490	1,945
	21	37	1,455	0	490	1,945
Overhaul of mooring	40	BM16	1,350	740	20	2,110
	31	16	1,480	635	10	2,125
	35	34	2,020	1,045	185	3,250
	33	35	2,020	1,155	165	3,340
	33	36	2,020	1,155	165	3,340
	34	37	2,020	1,045	150	3,215
Reinstallation of mooring	34	BM16	1,425	0	395	1,820
	47	16	2,490	40	635	3,165
	44	34	3,285	15	825	4,125
	43	35	3,285	0	1,060	4,345
	43	36	3,285	0	1,060	4,345
	45	37	3,285	35	870	4,190
Telephone removal and installation	0	BM16	0	0	0	0
	0	16	0	0	0	0
	0	34	0	0	0	0
	4	35	80	295	0	375
	4	36	80	295	0	375
	0	37	0	0	0	0
Total work		BM16	3,780	740	810	5,330
		16	4,985	695	1,095	6,775
		34	6,760	1,060	1,505	9,325
		35	6,840	1,450	1,715	10,005
		36	6,840	1,450	1,715	10,005
		37	6,760	1,080	1,510	9,350

[a] Mostly equipment rental costs.

Table 23. Maintenance and Replacement Costs for Moorings With and Without Cathodic Protection[a]

Year	Cost ($) for—					
	Mooring Without Cathodic Protection			Mooring With Cathodic Protection		
	Code[b]	Class BB (8 legs)	Class D (3 legs)	Code[b]	Class BB (8 legs)	Class D (3 legs)
0	–	0	0	D	9,000	4,500
1	A	500	350	A	500	350
2	A	500	350	A	500	350
3	B1, A	10,500	5,700	A	500	350
4	A	500	350	A	500	350
5	A	500	350	B2, A	1,100	885
6	B1, A	10,500	5,700	A	500	350
7	A	500	350	A	500	350
8	A	500	350	A	500	350
9	B1, A	10,500	5,700	A	500	350
10	A	500	350	A, B2, D	10,100	4,850
11	A	500	350	A	500	350
12	B1, A	10,500	5,700	A	500	350
13	A	500	350	A	500	350
14	A	500	350	A	500	350
15	C, A	70,500	27,350	B2, A	1,100	885
16	A	500	350	A	500	350
17	A	500	350	A	500	350
18	B1, A	10,500	5,700	A	500	350
19	A	500	350	A	500	350
20	A	500	350	A, B2, D	10,100	4,850
21	B1, A	10,500	5,700	A	500	350
22	A	500	350	A	500	350
23	A	500	350	A	500	350
24	B1, A	10,500	5,700	A	500	350
25	A	500	350	B2, A	1,100	885
26	A	500	350	A	500	350
27	B1, A	10,500	5,700	A	500	350
28	A	500	350	A	500	350
29	A	500	350	A	500	350
30	C, A	70,500	27,350	A, B2, D	10,100	4,850
Total		235,000	107,300		54,600	30,105

[a] Assuming new mooring at the start.

[b] See Table 24 for type of maintenance.

Table 24. Cost Value Assumptions

(Data compiled from San Diego moorings)

Code	Item	Cost ($) for Mooring—			
		With Cathodic Protection		Without Cathodic Protection	
		Class BB (8 legs)	Class D (3 legs)	Class BB (8 legs)	Class D (3 legs)
A	Annual in-place maintenance (for example, inspection, realignment, lighting repair)	500	350	500	350
	Removal, overhaul, and reinstallation				
B1	Every 3 years (entire mooring)	–	–	10,000	5,350
B2	Every 5 years (buoy only)	600	535	–	–
C	Replacement of deteriorated mooring chain and overhaul of buoy every 15 years (assuming no scrap value)	–	–	70,000	27,000
D	Anode installation at beginning and replacement every 10 years (conservative estimate). (Assume indefinite life for ground tackle)	9,000	4,500	–	–

Table 25. Present Value and Equivalent Annual Payment for Moorings

(Values computed from Table 23)

Type of Mooring	Cathodic Protection	Present Value, P ($)	Equivalent Annual Payment, N ($)
Class BB (8 legs)	without	99,193	6,453
	with	29,355	1,910
Class D (3 legs)	without	46,892	3,050
	with	16,215	1,055

FINDINGS

1. A cathodic protection system utilizing specially cast zinc anodes on links in the ground tackle has provided a Fleet mooring in San Diego Bay with 3-1/2 years of protection from corrosion.

2. After 3-1/2 years of service, about one-third of the zinc has been lost from the anodes located on the buoy, and about one-tenth of the zinc has been lost from the anodes located on the ground tackle.

3. The cathodic protection system performed well with the ground legs on either a sandy or a muddy bottom.

4. A steel ground cable was woven through the ground tackle and periodically attached to it in order to achieve a thorough distribution of the cathodic potentials.

CONCLUSIONS

1. The NCEL-developed cathodic protection system that contains specially cast zinc anodes on links in the ground tackle and steel cables woven through the links to provide continuity for the cathodic potentials can completely protect from corrosion the underwater portion of a mooring buoy and its ground tackle for at least 10 years before anode replacement is necessary.

2. Such a cathodic protection system can result in considerable savings in the maintenance of Fleet moorings.

RECOMMENDATIONS

1. The presently designed cathodic protection system should be widely used throughout the Naval Shore Establishment.

2. Further limited effort should be made to determine if a simpler system of securing zinc anodes to mooring chairs can be devised.

ACKNOWLEDGMENT

Personnel at Navy Public Works Center, San Diego were most helpful in providing technical support and cost data.

REFERENCES

1. I. D. G. Graham. "The cathodic protection of buoys," Dock and Harbour Authority, vol. 38, no. 413, Sept. 1957, pp. 189-190.

2. Naval Civil Engineering Laboratory. Technical Report R-246: Protection of mooring buoys, Part I. Initiation of field testing, by R. W. Drisko and R. L. Alumbaugh. Port Hueneme, Calif., June 1963. (AD 411426)

3. ———. Technical Report R-258: Protection of mooring buoys, Part II. First rating inspection, by R. W. Drisko. Port Hueneme, Calif., Oct. 1963. (AD 421416)

4. ———. Technical Report R-291: Protection of mooring buoys, Part III. Second rating inspection, by R. W. Drisko. Port Hueneme, Calif., Apr. 1964. (AD 438211)

5. ———. Technical Report R-316: Protection of mooring buoys, Part IV. Results of third rating inspection, by R. W. Drisko. Port Hueneme, Calif., June 1964. (AD 443376)

6. ———. Technical Report R-355: Protection of mooring buoys, Part V. Fourth rating inspection, by R. W. Drisko. Port Hueneme, Calif., Jan. 1965. (AD 611410)

7. ———. Technical Report R-385: Protection of mooring buoys, Part VI. Results of fifth rating inspection, by R. W. Drisko. Port Hueneme, Calif., June 1965. (AD 616886)

8. ———. Technical Report R-431: Protection of mooring buoys, Part VII. Results of sixth rating inspection, by R. W. Drisko. Port Hueneme, Calif., Dec. 1965. (AD 624799)

9. ———. Technical Report R-458: Protection of mooring buoys, Part VIII. Results of seventh rating inspection, by R. W. Drisko. Port Hueneme, Calif., June 1966. (AD 636422)

10. ———. Technical Report R-531: Protection of mooring buoys, Part IX. Results of eighth rating inspection, by R. W. Drisko. Port Hueneme, Calif., June 1967. (AD 654173)

11. ———. Technical Report R-542: Protection of mooring buoys, Part X. Results of ninth rating inspection, by R. W. Drisko. Port Hueneme, Calif., Sept. 1967. (AD 659478)

12.——. Technical Report R-585: Protection of mooring buoys, Part XI. Results of tenth (final) rating inspection, by R. W. Drisko. Port Hueneme, Calif., June 1968. (AD 834980L)

13.——. Technical Report R-097: Corrosion survey of steel piling, by C. V. Brouillette and A. E. Hanna. Port Hueneme, Calif., Dec. 1960.

14. A. J. Seabrook. "Corrosion problems and cathodic protection," Dock and Harbour Authority, vol. 45, no. 529, Nov. 1964, pp. 215-217.

15. Peterson, M. H. and L. J. Waldron. "Investigation of mild steel corrosion rates in San Diego Harbor," Corrosion, vol. 17, no. 4, April 1961, pp. 188t-190t.

16. Naval Civil Engineering Laboratory. Technical Report R-365: Plastic mooring buoys, Part 1. Fabrication of experimental models, by R. W. Drisko and T. Roe. Port Hueneme, Calif., March 1965. (AD 612055)

17.——. Technical Report R-601: Plastic mooring buoys, Part II. Completion of test program, by R. W. Drisko. Port Hueneme, Calif., Nov. 1968. (AD 845132)

18.——. Technical Report R-655: Plastic mooring buoys. Cost and additional performance data, by R. W. Drisko. Port Hueneme, Calif., Jan. 1970. (AD 701367)

DISTRIBUTION LIST

SNDL Code	No. of Activities	Total Copies	
–	1	20	Defense Documentation Center
FKAIC	1	10	Naval Facilities Engineering Command
FKNI	6	6	NAVFAC Engineering Field Divisions
FKN5	9	9	Public Works Centers
FA25	1	1	Public Works Center
–	9	9	RDT&E Liaison Officers at NAVFAC Engineering Field Divisions and Construction Battalion Centers
–	260	260	NCEL Special Distribution List No. 5 for persons and activities interested in reports on Deterioration Control

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Naval Civil Engineering Laboratory
CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS (Final), by R. W. Drisko
TR-702 53 p. illus November 1970 Unclassified

1. Cathodic protection system 2. Fleet moorings I. YF 51.543.006.01.007

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Civil Engineering Laboratory Port Hueneme, California 93041	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

CATHODIC PROTECTION SYSTEM FOR FLEET MOORINGS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final; January 1964 to February 1970

5. AUTHOR(S) (First name, middle initial, last name)

R. W. Drisko

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1970	53	18

8a. CONTRACT OR GRANT NO. b. PROJECT NO. YF 51.543.006.01.007 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TR-702 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Facilities Engineering Command Washington, D. C. 20390

13. ABSTRACT

A cathodic protection system was developed for protecting from corrosion both the underwater portion of a mooring buoy and its ground tackle. The final design of this system protected both buoy and chain for 3-1/2 years, and sufficient zinc appeared to remain for at least another 6-1/2 years of protection. The system performed well on both a sandy and a muddy bottom. The zinc anodes used on the ground tackle were specially cast on steel chain links to become an integral part of the chain system. The tight riser-chain secured to the peg-top buoy had the required electrical continuity to permit the necessary flow of current for protection, but it was necessary to use a steel cable woven through the links of each ground leg to achieve electrical continuity there. A cost analysis indicates that use of such a cathodic protection system can result in a considerable reduction in costs associated with maintenance of Fleet moorings.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fleet moorings						
Cathodic protection						
Corrosion						
Buoys						
Ground tackle						
Zinc anodes						
Steel cables						
Cathodic potentials						
Sinker blocks						
Sea chests						
Ground cables						
Silver soldering						
Chain links						
Riser chain						

DD FORM 1 NOV 65 1473 (BACK)

(PAGE 2)

Unclassified

Security Classification